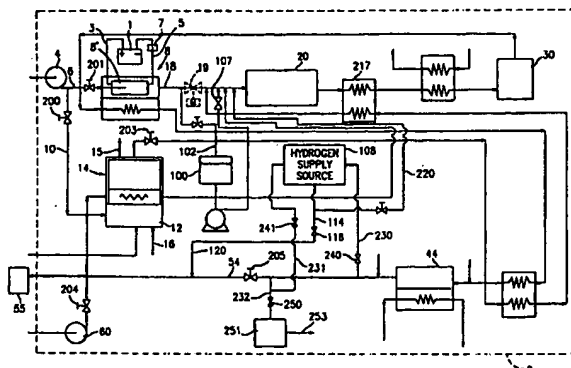




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(21) International Application Number: PCT/US99/30264 (22) International Filing Date: 17 December 1999 (17.12.99) (30) Priority Data: 09/221,428 28 December 1998 (28.12.98) US (71) Applicant: INTERNATIONAL FUEL CELLS, LLC [US/US]; 195 Governor's Highway, South Windsor, CT 06074 (US). (72) Inventors: LESIEUR, Roger, R.; 14 Van Buren Road, Enfield, CT 06082 (US). BONVILLE, Leonard, J., Jr.; 19 Buck- board Lane, Marlborough, CT 06447 (US). GAROW, Jay; 22 Bette Circle, Vernon, CT 06066 (US). CORRIGAN, Thomas, J.; 188 Rainbow Trail, Vernon, CT 06066 (US). PRESTON, John, L., Jr.; 105 Yorkshire Drive, Hebron, CT 06248 (US). (74) Agent: KELLY, Robert, H.; International Fuel Cells, LLC, Intellectual Property Counsel, 195 Governor's Highway, South Windsor, CT 06074 (US).		(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZA, ZW, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE). Published <i>With international search report.</i> <i>Before the expiration of the time limit for amending the</i> <i>claims and to be republished in the event of the receipt of</i> <i>amendments.</i>

(54) Title: SYSTEM FOR OPERATION AND START-UP OF A VEHICLE POWERED BY A FUEL CELL

**(57) Abstract**

A fuel gas processing system (2) operable to remove substantially all of the sulfur present in a hydrocarbon fuel supply used to power a fuel cell power plant (55) in a mobile vehicular environment. The fuel can be gasoline, diesel fuel, kerosene, fuel oil, natural gas, or another fuel which contains relatively high levels of organic sulfur compounds. The fuel supply is passed through a nickel reactant desulfurizer bed (8) wherein essentially all of the sulfur in the organic sulfur compounds react with the nickel reactant, and are converted to nickel sulfide. The fuel cell power plant and the fuel processing system can be used to power a mobile vehicle. An auxiliary supply (108) of hydrogen is provided in order to power the fuel cell during start up of the fuel processing system. A second auxiliary supply (100) of desulfurized fuel is also provided to operate the fuel cell during an interim period until the highest temperature of the fuel processing system is brought up to a final operational temperature.

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Description

SYSTEM FOR OPERATION AND START-UP OF A VEHICLE POWERED BY A FUEL CELL

Technical Field

- 5 The present invention relates to an improved system for use in a fuel cell power plant assembly which is used to power a vehicle. More particularly, the system of this invention allows the fuel cell power plant assembly to be used to enable the vehicle to be started up without undue delay.

Background of the invention

- 10 Assemblies of fuel cells, called cell stack assemblies (CSA), have been used for some time as power sources for stationary fuel cell power plants in units such as ONSI's PC25 power plant; and they have also been used as power sources in space for NASA's Space Shuttle orbiter vehicle which is powered by International Fuel Cells Corporation's PC17 power plant. In view of their size, weight and/or cost, neither of
15 these units is adaptable for use in a mobile vehicle application; however experimental units are being developed for use in mobile vehicles that will meet the size, weight and cost requirements and will also run on a reformable fuel, such as gasoline, diesel fuel, or the like.

- A primary operating parameter that must be addressed in the use of a fuel cell power
20 plant in a mobile vehicle is the start-up sequence. For example, the aforesaid PC25 power plant requires about three hours to achieve startup conditions; while the orbiter PC17 unit requires less than an hour to achieve startup conditions. Neither of these startup time requirements is acceptable for a mobile vehicle application. A fuel cell
25 powered mobile vehicle must be able to be started as easily as an internal combustion engine-powered vehicle, which is ready to operate as soon as the ignition is turned on. Thus, the development of a system with instant ignition response at vehicle start-up is a necessary objective for a fuel cell power plant system that is able to be used to power a conventional mobile vehicle, such as an automobile, bus, truck, or an aquatic vehicle such as a boat.

The fuel cell CSA of a fuel cell power plant, especially a PEM type fuel cell which operates at relatively low temperatures, can be designed to deliver startup power evenly before achieving full CSA operating temperatures. Yet, to have a fuel cell powered vehicle system that runs on reformat gas operate instantly at start-up, one
5 needs a system operating method for the initial transient time required to start the fuel processing unit. The key elements of the fuel processing unit, i.e., the sulfur scrubber and reformer, take a finite amount of time to be raised to their predetermined operating temperatures, while at the same time, the vehicle is required to operate according to the driver's demands without delay. One approach
10 followed by some experimental developers is to eliminate the fuel processing problem by defining the power plant solely as a pure hydrogen fuel unit. Since gasoline is the most generally available fuel for vehicular use, a fuel cell power plant that can use gasoline, or similar commonly available vehicle fuels would be most desirable.

Since gasoline or similar fuels are preferred for vehicular applications, it is necessary
15 to employ a fuel processing technique that can readily convert these fuels into a hydrogen-rich fuel stream while also lending itself to a light weight and compact design. An autothermal fuel processing unit, as described in U.S. Patent No. 4,473,543, is such a device. It can operate in a temperature range which is suitable for processing gasoline and is also easily configured into a small compact unit which
20 is suitable for vehicular use.

While gasoline is considered to be the fuel of choice, circumstances may warrant the use of other fuels such as natural gas, propane or methanol, for example. With these other fuels, the fuel processing system would continue to include an autothermal reformer because of size and weight benefits.

25 Therefore what is needed is a fuel cell power plant for vehicles that starts instantly and uses a fuel processing unit which is light weight, compact and capable of processing gasoline, or the like fuels which contain sulfur compounds. This would be highly desirable from an environmental viewpoint in the reduction of pollutants and a more efficient use of natural resources.

Disclosure of the Invention

This invention relates to a fuel cell power plant system which is suitable for use in a mobile or aquatic vehicle, and which is capable of being instantly started up, and is capable of processing fuels such as gasoline, and other commonly available fuels
5 which contain sulfur compounds. The invention can also process fuel supplies, such as methanol, which are sulfur-free, but which may become contaminated by sulfur during shipping or filling. The instant start-up systems of this invention can be incorporated into fuel processing systems described in commonly owned co-pending application for Letters Patent USSN 09/104,254, filed June 24, 1998. Such instant
10 start-up can be accomplished by having a system that incorporates on-board auxiliary fuel supplies for system operation during a start-up period, which auxiliary fuel supplies are sufficient to bring the fuel processing components up to system operating temperatures. When methanol is the fuel being processed, the system would not require a sulfur scrubber, but other components of the system would
15 remain the same.

The system of this invention can include an auxiliary onboard fuel supply which allows the fuel cell CSA to operate, while the key elements of the fuel processing unit, i.e., the sulfur scrubber and the reformer are raised to their operating temperatures. This onboard fuel supply, which is typically hydrogen, can be
20 regenerated during normal operation of the power plant since excess processed fuel is available during much of the vehicle driving cycle.

The system of the invention also includes a reformer unit, typically an autothermal reformer, which is designed to process fuels such as gasoline, or the like. The reformer can achieve its operating temperatures before the sulfur scrubber, so that
25 the reformer fuel processing can be started first. This is accomplished by having an onboard supply of available fuel to operate the reformer while the sulfur scrubber continues its heat up process. The auxiliary fuel supply can be desulfurized gasoline supply which will be used so that the vehicle can operate on the auxiliary supply until the sulfur scrubber is operational, and the complete system starts to perform.

30 It is therefore an object of this invention to provide a system which is suitable for use in a mobile electrically-powered vehicle which is powered by electricity provided by a

fuel cell power plant on the vehicle.

It is an additional object of this invention to provide a system of the character described wherein a raw hydrocarbon fuel stock is desulfurized to an extent needed to produce a gaseous fuel cell power plant-compatible fuel stream.

- 5 It is a further object of this invention to provide a system of the character described wherein the vehicle can be started by means of an auxiliary source of fuel suitable for use in the fuel cell power plant, without significant fuel processing.

These and other objects of the invention will become more readily apparent from the following detailed description thereof when taken in conjunction with the
10 accompanying drawings in which:

Brief Description of the Drawings

FIG. 1 is a schematic drawing of a fuel processing system designed for use in a vehicle which incorporates the instant start-up system of this invention;

- 15 FIG. 2 is an embodiment of the system of this invention which operates the cell stack assembly with hydrogen until the reformer is brought up to operating temperatures;

FIG. 3 is a software flow chart indicating the mode of operation of the various valves used in the instant start-up system of this invention; and

FIG. 4 is a perspective view of an embodiment of a sulfur scrubber bed which is compact and very light weight while providing optimal reactant surface area.

20 Specific Modes for Carrying Out the Invention

- Referring now to the drawing, FIG. 1 is a schematic view of a fuel processing system that is denoted generally by the numeral 2 and which is suitable for use in a vehicle such as an automobile. The fuel being processed, as noted above, can be gasoline, which shall be specifically referenced hereinafter as a preferred mode for practicing
25 the invention. A fuel pump 4 pumps the gasoline into the system 2 via line 6 which leads to a nickel reactant desulfurizer bed 8. A branch line 10 is provided to bleed off a portion of the gasoline to feed a burner 12 in a boiler 14 which produces steam for

the fuel processor system 2. Air enters the burner 12 through line 16. The burner exhaust exits from the system 2 via an exhaust line 15. In normal operation, the fuel flows from the desulfurizer bed 8 into the autothermal reformer 20 wherein the fuel is initially converted into a hydrogen-rich gas. From the reformer 20 the gas may pass through one or more heat exchangers and then to a shift converter 30 where the gas is further processed to increase the amount of hydrogen in the gas stream. Following the shift converter 30, the gas stream may again pass through various heat exchangers, and then to a selective oxidizer 44 having one or more beds, after which the gas flows to the CSA 55 via line 54.

- 10 The system 2 is provided with a reserve supply of fuel so as to enable the vehicle to be readily restarted after shut down of a previous operating cycle. In one embodiment, a start-up supply of desulfurized fuel is drawn off into a start-up fuel tank 100 during each operating cycle of the system 2. The start-up desulfurized reserve fuel supply is maintained in a liquid form in the tank 100. The valve 19 is employed in the line 18 to maintain the liquid phase of the fuel in the desulfurizer 8. The liquid desulfurized fuel reserve is drawn into the tank 100 through a branch line 102 which communicates with the line 18 upstream of the valve 19. Thus the reserve supply 100 of desulfurized fuel can be used to operate the reformer 20 on a temporary basis, after the reformer 20 is at its operating temperature and until the desulfurizer 8 has reached its operating temperature.

- For an instant response start-up of the power plant, an additional, or supplemental start-up sub-assembly may also be incorporated into the system. This additional sub-assembly includes a hydrogen supply source 108, which could be a pressurized tank or a hydride bed containing hydrogen. The hydrogen supply source is connected to an outlet line 114 which leads to line 120 that is connected to the line 54. Valve 116 controls the passage of hydrogen through the line 120 so that hydrogen can be selectively fed to the fuel cell stack assembly 55 to operate the latter during start up of the vehicle until the system 2 is brought to operating temperature by any of the systems described in this application. The hydrogen supply can be replenished during power plant operation by manipulating valves 240 and 241 in lines 230 and 231. The reformer heat up could be accomplished by several methods such as a gasoline and air fired heat exchanger as shown in FIG. 2, or by directly supplying hydrogen and air to the system, as described in FIG. 1.

FIG. 2 shows a sub-system which can be used to bring the reformer 20 to operating temperature while the cell stack assembly 55 is being operated with hydrogen from the tank 108 during start up. A pump 210 is provided for pumping ambient air into a line 211 leading to a burner 212. The fuel pump 4 is selectively operable through opening of a valve 215 to pump raw gasoline through line 213 to the burner 212 wherein the gasoline and air are burned to produce a hot gas that is directed into a heat exchanger 216 in the autothermal reformer 20. The flow of heated gas through the heat exchanger is continued until the autothermal reformer 20 reaches an initial temperature of about 450°F. At the same time, the valve 201 remains closed and the valve 200 is opened so as to fire up the boiler 14 while preventing the flow of raw gasoline to the reformer 20.

Once the reformer temperature is at about 450°F, as seen in FIG. 1, heat to the reformer 20 is continuously generated by a combination of steam from the boiler 14 via valve 203, and air via valve 204, and by desulfurized fuel via valve 107 while the fuel cell stack 55 continues operating from the H₂ supply. The effluent from the reformer 20 is then fed to the other components in the fuel processing system in order to bring them up to operating temperature. The effluent vents from the power plant through line 232, which is controlled by valve 250, and passes into a catalytic burner 251, from which the effluent is exhausted into the ambient atmosphere through line 253. This transient state continues until the shift converter 30 is at an operating temperature of about 300-450°F.

As the shift converter 30 reaches a temperature of about 300-450°F, the fuel processing system 2 moves to the next transient state. The H₂ fuel supply to the fuel cell 55 is replaced by output from the system 2 by opening the valve 205 and by closing the valve 116. This transient state continues until the desulfurizer reaches a temperature of about 350°F. Once that temperature is reached, the desulfurized fuel supply is shut off by closing valve 107 while the raw fuel supply is started by opening valve 201. At this point in time, the entire system is in operation.

Referring now to FIG. 3, there is shown the start up operational program by which the system controller operates the system. It will be noted that Block A represents the shutdown state of the power plant including the cell stack assembly and of the fuel

processing system. In Block B, the system has been alerted that a power plant start-up is imminent. Block C shows the initiation of transient state 1 where the cell stack assembly 55 is supplied with hydrogen from source 108 while the boiler 14 and reformer start-burner 12 begin operation. State 1 is initiated as noted in Block C by opening the valves 116, 200 and 215 and starting blower 210 so as to supply the boiler burner 12 with fuel, and to supply the air and fuel to the reformer burner 20 which heats the reformer 20 through the reformer start-up HEX 216. Exhaust gas from the HEX 216 can be used to heat the steam superheater HEX 217 by flowing the exhaust gas through the superheater HEX 217. Transient state 1 is continued until the autothermal reformer 20 has reached a temperature of about 450°F, as noted by Block D.

Block E shows the initiation of transient state 2. In this state, the cell stack assembly 55 continues to be supplied with hydrogen from source 108 while steam from the boiler 14, air from a blower 60, and desulfurized fuel from the tank 100 begin flowing into the reformer by opening valves 107, 203 and 204. At the same time, valve 215 closes to stop the flow of raw fuel to the reformer burner 212 through line 213. The exhaust from the autothermal reformer 20 continues through the remaining fuel processing system components in order to heat them to operating temperature. Transient state 2 is continued until the shift converter has reached a temperature of about 350°F, as noted by Block F.

Block G shows the initiation of transient state 3. In this state, the cell stack assembly 55 is switched from the H₂ supply source 108 to operation on the output from the fuel processing system 2. The switch is made by opening valve 205 and closing valves 116 and 250. Transient state 3 is continued until the desulfurizer 8 has reached a temperature of about 350°F, as noted by Block H.

Block I shows the initiation of the normal operating mode wherein the fuel processing system 2 is switched from the desulfurized fuel supply to the raw fuel supply. This is accomplished by opening valve 201 and closing valve 107. The normal state of operation remains in effect until the next shut down cycle begins.

Referring to FIG. 4, there is shown an embodiment of a sulfur scrubber reactant bed component 8' which takes the form of a monolithic open-cell sponge or foam formed

from a material such as aluminum, copper, or ceramic which can be coated with a nickel reactant that will remove sulfur from a fluid passing through the component 8. The component 8' is formed by immersing or spraying the wash coated open cell sponge component 8' so as to form a high surface area nickel reactant layer.

- 5 The result is a compact light, weight, porous monolithic structure having interstices which are coated with the nickel reactant. This structure provides a high nickel-coated surface area with minimum weight and minimum size. This structure is much more desirable than nickel doped carbon pellets formed from nickel doped carbon powder, since most of the nickel in the doped powder is contained inside of the
- 10 pellets and will not encounter the sulfur-contaminated fluid which passes through the pellet bed. Suitable monolithic aluminum foam cores can be obtained from Energy Research and Generation, Inc. of Oakland, California. When the desulfurizer bed 8 is formed from the aforesaid nickel-coated monolithic foam component 8', the temperature of the desulfurizer bed 8 can be brought up to operational levels by
- 15 passing an electrical current through the component 8' and relying on current flow resistance. After system operating temperatures are stabilized, the electrical current is turned off. Referring back to FIG. 1, there is shown a sub-assembly for supplying the aforesaid heating current to the component 8'. The sub-assembly includes the vehicle battery 1 which is connected to the component 8' by means of lines 3 and 5.
- 20 A switch 7 selectively controls the flow of current through the component 8'.

It will be readily appreciated that the start up system of this invention will enable rapid start up of a power plant from a dormant state, so as to allow the cell stack assembly to supply electrical power to an electric motor in a vehicle. The start up supply of hydrogen and/or desulfurized fuel can be periodically recharged during operation of

25 the vehicle.

Since many changes and variations of the disclosed embodiment of the invention may be made without departing from the inventive concept, it is not intended to limit the invention otherwise than as required by the appended claims.

Claims

1. A system for implementing quick start-up of a vehicle that is powered by electricity derived from an onboard fuel cell power plant, said system including:
 - a) a source of a hydrocarbon fuel which contains organic sulfur compounds, said fuel serving as a hydrogen source for the fuel cell power plant during extended use of the vehicle;
 - b) a nickel reactant desulfurizer station which is operable to treat an undiluted stream of said hydrocarbon fuel so as to convert essentially all of the sulfur in said organic sulfur compounds to nickel sulfide thereby creating a substantially sulfur-free hydrocarbon fuel;
 - c) first means for reforming the sulfur-free hydrocarbon fuel to provide a hydrogen-enriched gaseous fuel stream;
 - d) second means for converting carbon monoxide and water in said hydrogen-enriched gaseous fuel stream to carbon dioxide and hydrogen;
 - e) third means for converting carbon monoxide and oxygen from said hydrogen-enriched gaseous fuel stream to carbon dioxide; and
 - f) an auxiliary fuel supply for use in temporarily operating said fuel cell power plant during start-up of said vehicle until proper operating temperatures are reached in said first, second and third means.
2. The system of Claim 1 wherein said auxiliary fuel supply is a supply of hydrogen.
3. The system of Claim 1 wherein said auxiliary fuel supply includes a choice of desulfurized hydrocarbon fuel and hydrogen.
4. The system of Claim 1 wherein said auxiliary fuel supply is a supply of desulfurized hydrocarbon fuel.
5. A method for implementing quick start-up of a vehicle that is powered by electricity derived from an onboard fuel cell power plant, said method comprising:
 - a) a first step of providing a source of a hydrocarbon fuel which contains organic sulfur compounds, said fuel serving as a hydrogen source for the fuel cell power plant during extended use of the vehicle;
 - b) a second step of providing a nickel catalyst desulfurizer station which is operable

- to treat an undiluted stream of said hydrocarbon fuel so as to convert essentially all of the sulfur in said organic sulfur compounds to nickel sulfide thereby creating a substantially sulfur-free hydrocarbon fuel;
- 10 c) a third step of reforming the sulfur-free hydrocarbon fuel to provide a hydrogen-enriched gaseous fuel stream;
- d) a fourth step of converting carbon monoxide in said hydrogen-enriched gaseous fuel stream to carbon dioxide; and
- e) a fifth step of providing an auxiliary fuel supply for use in temporarily operating said
- 15 fuel cell power plant during start-up of said vehicle until said proper operating temperatures are reached so as to implement said first, second and third steps.

6. The method of Claim 5 wherein said auxiliary fuel supply is a supply of hydrogen.

7. The method of Claim 5 wherein said auxiliary fuel supply includes a choice of desulfurized hydrocarbon fuel and hydrogen.

8. The method of Claim 5 wherein said auxiliary fuel supply is a supply of desulfurized hydrocarbon fuel.

9. A system for implementing quick start-up of a vehicle that is powered by electricity derived from an onboard fuel cell power plant, said system including:
- a) a source of a sulfur-free hydrocarbon fuel, said fuel serving as a hydrogen source for the fuel cell power plant during extended use of the vehicle;
- 5 b) first means for reforming the sulfur-free hydrocarbon fuel to provide a hydrogen-enriched gaseous fuel stream;
- c) second means for converting carbon monoxide and water in said hydrogen-enriched gaseous fuel stream to carbon dioxide and hydrogen;
- d) third means for converting carbon monoxide and oxygen from said hydrogen-
- 10 enriched gaseous fuel stream to carbon dioxide; and
- e) an auxiliary fuel supply for use in temporarily operating said fuel cell power plant during start-up of said vehicle until proper operating temperatures are reached in said first, second and third means.

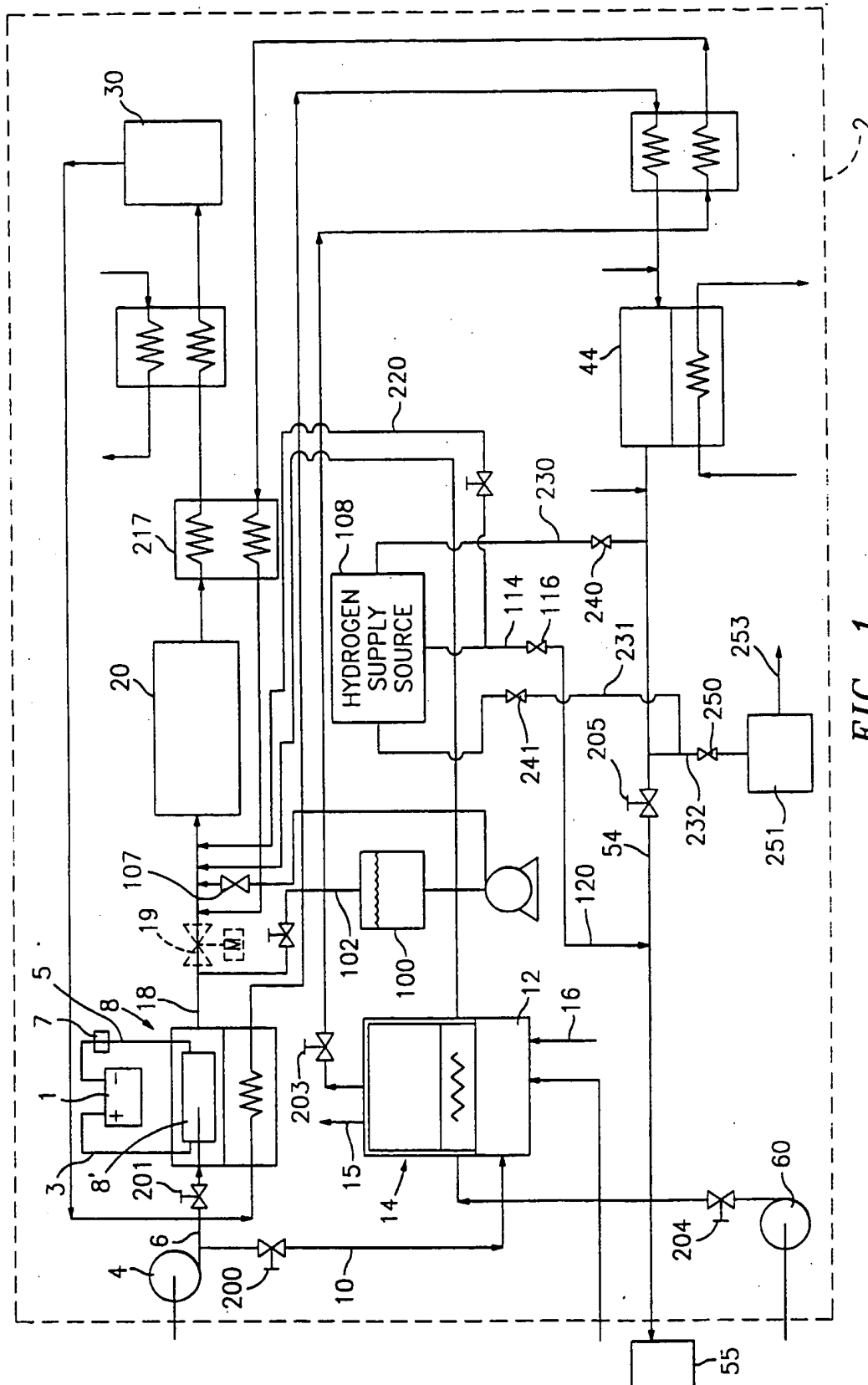
10. The system of Claim 9 wherein said auxiliary fuel supply is a supply of hydrogen.

11. The system of Claim 9 wherein said sulfur-free hydrocarbon fuel is methanol.

12. A sulfur scrubbing bed for removing sulfur from a hydrocarbon fuel so as to render the hydrocarbon fuel essentially sulfur-free, said bed comprising a monolithic open cell sponge substrate having interstices which are provided with a high surface area washcoat, the washcoated interstices of said substrate being coated with nickel.

13. A system for removing sulfur from a hydrocarbon fuel, said system comprising a sulfur scrubbing bed comprising:

- a) a monolithic open cell sponge substrate having interstices which are provided with a high surface area washcoat, the washcoated interstices of said substrate being
- 5 coated with nickel; and
- b) a source of electrical current connected to said bed for supplying electrical current which is operable to bring said bed up to operating temperatures.



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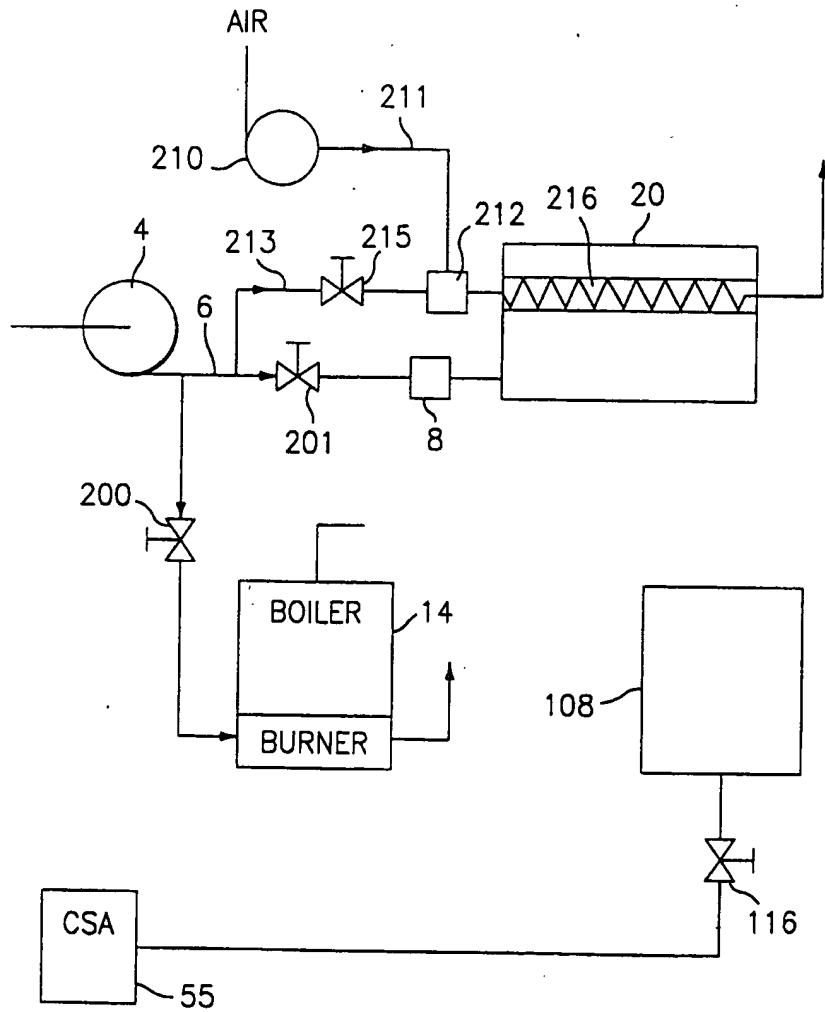


FIG. 2

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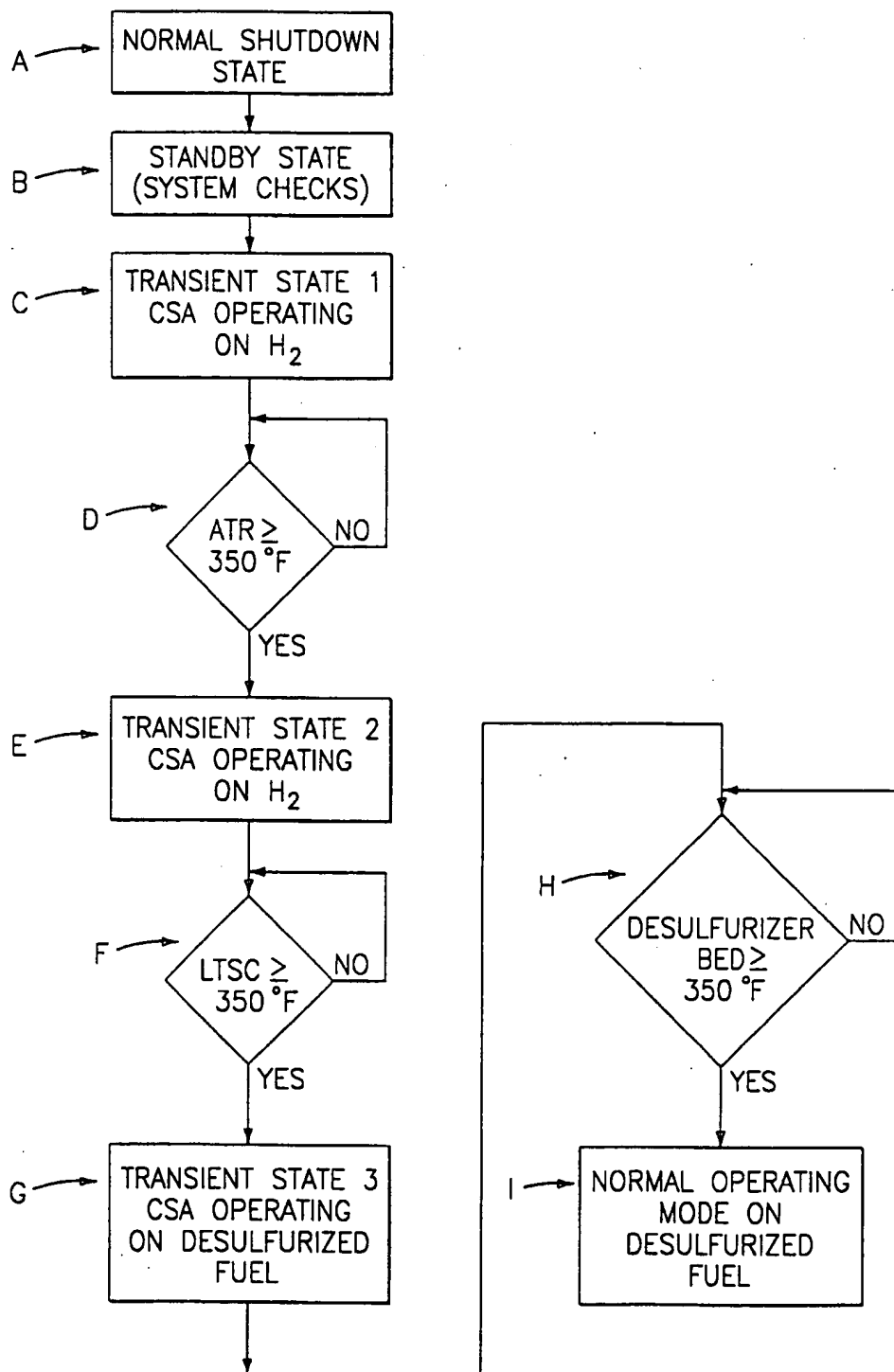


FIG. 3

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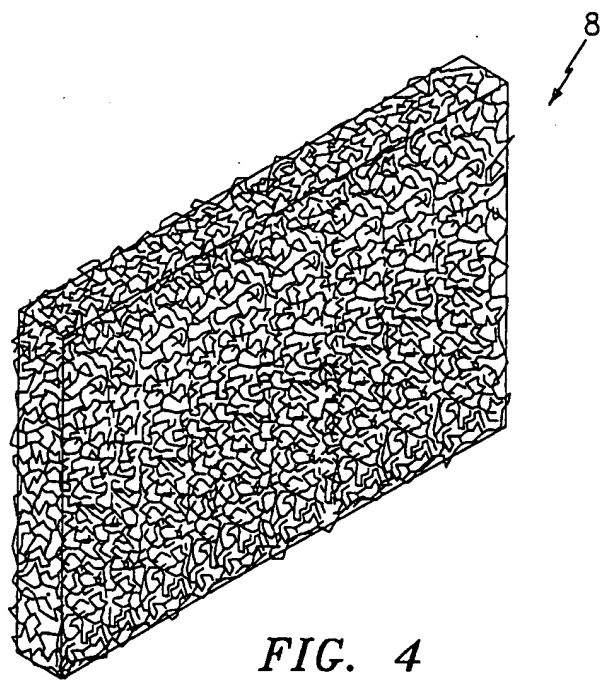
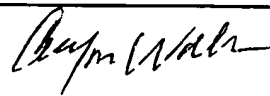


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/30264

A. CLASSIFICATION OF SUBJECT MATTER IPC(7) :H01M 8/04; B01J 20/02 US CL :429/17, 20; 502/406 According to International Patent Classification (IPC) or to both national classification and IPC																				
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) U.S. : 429/17, 20, 26, 120; 502/406 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)																				
C. DOCUMENTS CONSIDERED TO BE RELEVANT																				
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.																		
X	US 5,688,740 A (BOLSHAHKOV et al) 18 November 1997, col. 2, lines 27-67.	12																		
X	US 4,592,829 A (EBERLY) 03 June 1986, col. 6, lines 20-25, col. 7, lines 43-53.	12																		
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Y		13																		
Y	US 5,158,841 A (MENNICKE et al) 27 October 1992, col. 1, lines 13-19, col. 7, lines 20-25.	13																		
A,P	US 5,928,805 A (SINGH et al) 27 July 1999, col. 4, lines 18-21.	1-11																		
A	US 5,290,641 A (HARASHIMA) 01 March 1994, col. 1, lines 39-43.	1-11																		
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.																				
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Date of the actual completion of the international search 10 APRIL 2000		Date of mailing of the international search report 26 APR 2000																		
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230		Authorized officer STEPHEN J. KALAFUT  Telephone No. (703) 308-0661																		

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4,376,097 A (EMELOCK) 08 March 1983, col. 2, lines 23-27, figure 1.	1-11
A	US 4,994,331 A (COHEN) 19 February 1991, col. 2, lines 26-29.	1-13
A	US 3,982,962 A (BLOOMFIELD) 28 September 1976, col. 3, lines 13-17.	1-11

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